



Coastal Vulnerability Assessment for Eastern Coast of India, Andhra Pradesh by Using Geo-Spatial Technique

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Abstract

The study mainly deals with the physical vulnerability of eastern coast India, Andhra Pradesh. It is one of the Indian states which have a very vast coastal line. Andhra Pradesh is very important to the whole economy, Vishakhapatnam is a major port situated in the eastern coast of India. Andhra Pradesh coastal line about 972 Km long, is affected by Storm surge, Cyclone, Sea Level Rise and Tsunami, etc. The method adopted for identifying the coastal vulnerability mapping was Coastal Vulnerability Index (CVI). Seven parameters were used for identifying Coastal Vulnerability mapping which are Historical Shoreline changes, Mean Sea Level Rise, Significance of Wave Height, Mean Tide Range, Coastal Regional Elevation, Coastal Slope and Geomorphology. The final results of this study are in the form of a coastal vulnerability map which shows the environmentally vulnerable areas. This map will give general idea about the probability of an area to undergo coastal hazards due to coastal erosion or sea level rise. According to this study about 16% area of the coast of Andhra Pradesh is identified to have high vulnerability which can harm the environment. The map prepared of the Andhra coast under this study can be used by the state and district administration involved in the disaster mitigation and management plan.

Keywords

Shoreline change; Coastal vulnerability index; Coastal hazard, GIS

Introduction

Coastal Hazards are physical or natural phenomena that expose a coastal area to risk of property damage, loss of being and environmental declination. Short term coastal hazards last over periods of minutes to several days and examples include cyclones, tsunami and storm-surges. Long term coastal hazards develop incrementally over longer time periods and examples include erosion and sea level rise and gradual inundation.

Tremendous population and developmental process have been building in the coastal regions for the last 40 years. According to the report of the United Nations in 1992, more than 50 percentages of the world's population lives within the 60 km of a shoreline [1,2]. Also, urbanization and the fastest developments of coastal cities have been

dominant population trends over the last few years, leading to the development of mega cities in all coastal regions across the world. In 1950 there were only two mega cities in the world (New York and London), whereas there were 20 mega cities in 1990 [2,3]. It has been indicating that there will be 30 mega cities by 2010, having a population of 320 million people [2,3]. United Nations Environment Programme (UNEP) report is discussing that, the average population density in the coastal zone was 77/km² in 1990 and 87/km² in 2000, and a projected 99/km² in 2010 [4,5]. The scenario of people living in the coastal regions compared with available coastal lands further indicates that the people have tendency to live in coastal areas than inland.

There are several types of coastal environments in India with very different features that affect, influence, and change the near-shore processes that are involved. Understanding these environments and ecosystems can develop for mitigating techniques and policy-making efforts against natural and anthropogenic coastal hazards in these vulnerable areas.

The changes of coastal regions are dynamic process, thus, regular monitoring of coastal zone is very important. Moreover, preparation of an appropriate coastal zone management plans as well as implementation of regulations in the coastal zone require spatial information on the coastal land use and land forms along with tidal region, the inventory and status of coastal habitats and information on Ecologically Sensitive Areas. Remote sensing techniques have been widely used for analyzing, monitoring and management of natural resources in the coastal areas. Due to its repetitive, multispectral and synoptic nature, satellite Remote Sensing has proved to be tremendously useful in providing information on various aspects of the coastal environment, viz. coastal landforms, shoreline changes, tidal levels, early tsunami warnings, weather forecasting, suspended sediment dynamics, coastal currents, vital coastal habitats, etc.

Study Area

The state of Andhra Pradesh is located in the Indian sub-continent. It is one of the 29 states of India, lying on the southeastern coast of the country. It lies between 120 35' 23.67" and 190 10' 15.47" North Latitude and 760 44' 32.47" and 840 47' 33.88" E Longitude. Andhra Pradesh is sharing boundaries with Odisha in the northeast, Telangana in the northwest, Karnataka in the west, Tamil Nadu in the south, and Bay of Bengal in the east (Figure 1). It is the eighth largest state in the country covering an area of 160,205 km² (Administrative and Geographical Profile AP).

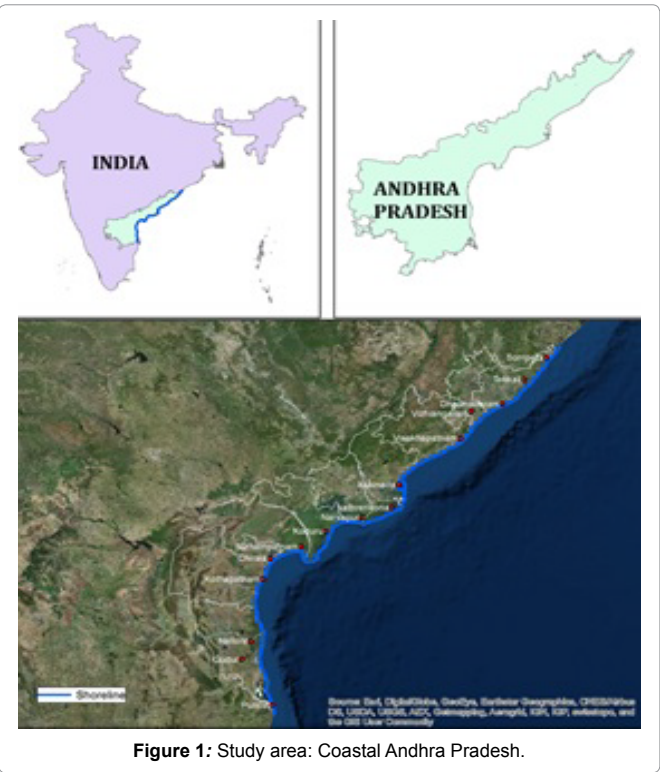
This state has the second longest coastline of 972 Km among all the states of India. Vishakhapatnam is the largest city and commercial hub of the state and it is a port that plays an important role in the economic activities in the country. Rajahmundry, Tirupati, Guntur, Kadapa, Kakinada, Nellore, Onmgole and Eluru are the other important places in the state.

Data and Methodology

The methodology of the current study is to envisage coastal vulnerability Assessment along the coast of Andhra Pradesh. It

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involves the assessment of shoreline change rate, mean sea level rise, mean tide range, significant wave height, coastal slope, geomorphology and coastal regional elevation (Figure 2) and various open source data were used to calculate vulnerability (Table 1). The methodology for coastal vulnerability assessment is the same as that used by Gornitz and Thieler [6,7] and various tools and techniques adopted from similar studies [2,8-10]. The data were collected for the months of November and December because the most of the disaster occurred between months of October to December. The shoreline change rate calculated over 43 years and other parameters calculated based on the data availability, some data were not available for a long period of time, such as significant wave height and Tidal range (Table 1).

Shoreline change assessment

Shoreline is the border of land at the edge of a large body of water, such as an ocean, sea, or reservoir. In physical oceanography, a shore is the wider border that is geologically modified by the action of the body of water past and present, while the beach is at the edge of the shore, representing the intertidal zone where there is one [11]. The geological composition of rock and soil dictates the type of shore which is created.

Shoreline was extracted from the basis of geospatial techniques by using the Landsat satellite data acquired from earth explorer pertaining to the period 1972-2015. There are two satellite images month of December were used for extracting shoreline which are Landsat 1-2 MSS and Landsat 8 OLI with 57 and 30 m resolution respectively (Table 1). In 1972 Landsat 1-2 MSS data were used and Landsat 8 OLI was used to extract 2015 shoreline. Shorelines correspond to individual period were generated using the on-screen point mode digitization technique by using the blue, green near infra-red bands separates land-water boundary distinctly. Further, the changes in shoreline through processes of accretion and erosion were analyzed

in a Geographic Information System (GIS) by measuring differences in shoreline locations using Digital Shoreline Analysis System (DSAS) [12]. Several statistical approaches are available within DSAS for both extracting shoreline positions and quantifying shoreline change. The end point rate (EPR) was used to estimate the shoreline change rate. EPR calculated by dividing the distance of shoreline movement by the time elapsed between the earliest and latest measurements (i.e., the oldest and the most recent shoreline). The major advantage of the EPR is its ease of computation and minimal requirement for shoreline data (two shorelines). The major disadvantage is that in cases where more than two shorelines are available, the information about shoreline behavior provided by additional shorelines is neglected. Thus, changes in sign or magnitude of the shoreline movement trend or cyclic of behavior may be missed.

Shoreline change rate calculated during the period 1972 to 2015. In the resulted data the negative and positive values in the result are depicting erosion and accretion respectively. The shoreline change rate was further categorized into five major classes (Table 2). No changes since the small change can be considered as the technological/source errors included this result.

Geomorphology

Coasts are dynamic systems that are continuously transforming over different temporal and spatial scales as a result of geomorphological and oceanographically changes [13,14]. Morphology of the coast plays an important role in determining the impact of sea-level rise or dynamic changes along the coast [15,16]. Landforms and the material that compose them reflect their relative responses to sea-level rise since every landforms offer certain degree of resistance to erosion [7]. Indian space research organization [17]

Table 1: Various data used for this study on costal vulnerability.

Parameter	Data Used	Resolution	Period
Shore-line change rate	LANDSAT 1-2 MSS LANDSAT 8 OLI	57 meter 30 meter	1972 2015
sea-level change rate	GLOSS data	-	2000- 2015
Coastal slope	GEBCO data	30 arc-sec	2014
Coastal regional elevation	ASTER data	1 arc-sec	2011
Significant wave height	INCOIS Wave rider	-	2005- 2015
Tidal range	INCOIS Tide gauge	-	2006- 2015
Geomorphology	BHUVAN Thematic map	LEVEL-II	2005

- = Not applicable

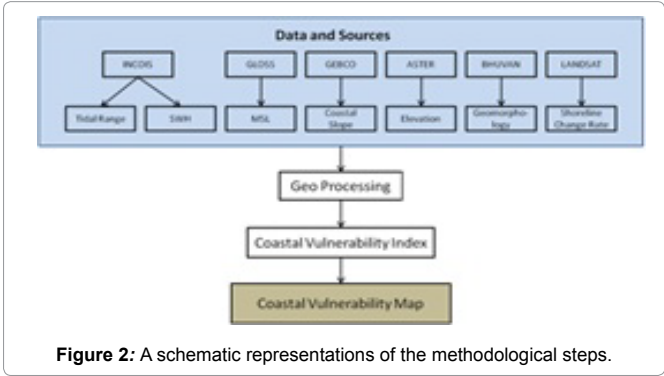


Figure 2: A schematic representations of the methodological steps.

and Bhuvan thematic map service were providing entire Andhra Pradesh geomorphology map with Level-II classification. These data were converted to vector data using ArcGIS and class the features on the basis of sensitivity. The coastline geomorphology has been categorized based on the dominant geomorphic class. The classes recorded in the study area include Deltas, structural origin features like dissected hills and valleys, coastal origin (deltaic plain, old coastal plain, young coastal plain), anthropogenic origin, deltas, lagoon, Sand beach, etc. On the basis of vulnerability, rocky cliffed coasts are categorized very low vulnerable, medium cliff and indented coasts are categorized low vulnerable. Alluvial plains are categorized on the medium vulnerable class. Lagoons, Estuary, Cobble beaches are classified high vulnerability and deltas, mangroves, coral reef, barrier beach, sand beaches are categorized on very high vulnerable. Ranking of deferent geomorphology classes were depicted in the table for the calculation of CVI (Table 2).

Regional elevation of the coast

It is important to study the coastal regional elevation detail for the study area to identify and estimated extend of land area threatened by future sea-level rise [2,18]. Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) data was used in the current study for the calculation of coastal regional elevation. One arc-sec (approximately 30 m) resolution aster data downloaded from earth explorer (USGS, METI and NASA) [19-22]. Then the data which elevation point extracted by intersection with shoreline. Further, the vulnerability classes have been assigned the coastline having low elevation as very high vulnerability and high elevation as low vulnerability. On the basis of vulnerability the area divided five classes, 0-3 m which very high vulnerable and 3-6 m high 6-10 m medium 10-13 m low above 30 very low this is also displayed in table (Table 2).

Coastal Slope

Coastal slope (steepness or flatness of the coastal region) is linked to the susceptibility of a coast to inundation by flooding [2,10,23]. The run-up of waves on a coast is the most important stage of a tsunami from the view point of the elevation of the level of tsunami hazard for the coast. Coastal slope characteristics are an important parameter in deciding the degree which coastal land is at risk of flooding from storm surges and during tsunami [9]. General Bathymetry chart of oceans [24] data 30 arc-sec grid resolution coastal topography and bathymetry has been used to get the regional slope of the coastal area. GEBCO Data are use full in deriving the coastal slope values on the both land and in the ocean. Slope is calculated by the help of Arc GIS tool. Coastal slope divided high to low vulnerable based on the degree of slope (Table 2).

Sea level change

Sea level, or 'mean sea level' as it is sometimes known, is the average height of the ocean's surface between high and low tide. Variations in

the gravitational acceleration are themselves caused by variations in the internal density of the Earth (British Geological Survey). Changes in tides and wave conditions over time are averaged out to determine a 'still water level' that can be used to identify whether the sea level has changed and also the height of the land above sea level.

Sea levels change for many reasons and over timescales that are very different. Sea levels are rising today not only because significant parts of the land-based ice are melting, but also because ocean waters are warming and therefore expanding.

Permanent Service for Mean Sea Level (PSMSL) data pertaining to study area and including adjoining areas hosted by Global Sea Level Observing System (GLOSS) on their website was used as the primary source of information for sea level trend. The monthly mean tide gauge data recorded within and adjoining tide stations were collected for the estimation of the sea level trends. There are 14 tide gauge data pertaining to last 10 year were collected for the study which are adjoining the study area. The data sea level trend pertaining to tide gauge stations were interpolated by krigging interpolation technique and the values along the coast were assigned the corresponding coastal segments using Arc GIS tool. The coasts recorded with high sea level rise were assigned high vulnerable and lower sea-level rise assigned low vulnerable (Table 2).

Mean tidal range

The tidal range is the vertical difference between the high tide and the succeeding low tide. Tides are the rise and fall of sea levels caused by the combined effects of the gravitational forces exerted by the Moon and the Sun and the rotation of the Earth [25]. The tidal range is not constant, but changes depending on where the sun and the moon are.

There are 13 tide gauge data we collected over 6 years data depicted in Bay of Bengal. From the data extracted high and low tide range occurred in December month and calculated mean tidal range from the extracted data, then generated raster data by krigging interpolation method with the help of Arc GIS tool. Then the data generated from the raster and intersect with shoreline. These values were further classified on the basis of vulnerability high tide range regions categorized as low vulnerability and low tide range regions as high vulnerability the vulnerable class and values are showing in the table (Table 2).

Significant wave height

In physical oceanography, the significant wave height (SWH or H_s) is defined traditionally as the mean wave height (trough to crest) of the highest third of the waves ($H_{1/3}$) [26]. Nowadays it is usually defined as four times the standard deviation of the surface elevation- or equivalently as four times the square root of the zeroth-order moment (area) of the wave spectrum. The symbol H_{m_0} is usually used

Table 2: Coastal vulnerable classes with parameters.

Sl. No.	Parameters	Very Low (1)	Low (2)	Moderate (3)	High (4)	Very High (5)
a	Shoreline change (M)	>10	2-10	-2-1.99	-10- -2	<-10
b	Costal Slope (Degree)	0-10	11-20	21-45	46-60	61-89
c	Costal Regional Elevation (M)	<3	4-10	11-20	21-38	>38
d	Mean Sea Level(M)	<1.8	1.81-2.5	2.51-2.95	2.96-3.16	>3.16
e	Mean Tide Range (M)	>4	2.1-4	1.81-2	1.51-1.8	<1.5
f	Mean Wave Height (M)	<0.42	0.42-0.6	0.61-0.78	0.79-0.84	>0.84
g	Geomorphology	Rocky, cliffed coast	M. Cliff, Indented Coasts	Alluvial Plain	Estury, Lagoon	Sand beach, Delta

for that latter definition. The significant wave height may thus refer to H_{m0} or $H_{1/3}$; the difference in magnitude between the two definitions is only a few percent.

Significant wave height data were collected from INCOIS (Indian National Centre for Ocean Information Services). Six wave rider buoy data were collected along the study area and adjacent stations since 2009. Extracted $H_{1/3}$ waves from the data using ferret data modeler. Further $H_{1/3}$ waves converted to NetCDF format and it is converted to raster format by the help of Arc GIS Tools, and the data further extracted to point data and intersect with shoreline. The highest wave height considered as very vulnerable and lowest became low vulnerable (Table 2).

Coastal vulnerability index

The coastal vulnerability index (CVI) presented here is the same as that used in similar studies [2,7,18]. The selected parameters are divided five classes based on the vulnerability from very low to very high (Table 2). The CVI allows the seven variables to be related in a quantifiable manner that expresses the relative vulnerability of the coast to physical changes due to future sea-level rise. This method yields numerical data that cannot be equated directly with particular physical effects. It does, however, highlight areas where the various effects of sea-level rise may be the greatest. Once each section of coastline is assigned a vulnerability value for each specific data variable, the coastal vulnerability index (CVI) is calculated as the square root of the product of the ranked variables divided by the total number of variables as.

$$CVI = \sqrt{(a * b * c * d * e * f * g) / 7}$$

Where,

a=shoreline erosion/accretion rate

b=coastal slope

c=coastal regional Elevation

d=Mean sea-level rise

e=mean tide range

f=mean wave height

g=geomorphology

Results and Discussion

Assessment of CVI and seven individual input parameters have been carried out along Andhra Pradesh coastline. These parameters reveal large variability due to physical or climatic changes over a long term period. Whereas the shoreline change was also recorded large variability reveal dynamic coastal processes along the coastline. Net shoreline change along the study area pertaining to 43 year was assessed during 1972-2015.

Shoreline changes

Changes in shoreline through processes of accretion and erosion can be analyzed in a geographic information system (GIS) by measuring differences in past and present shoreline locations. Very High erosion was recorded in Krishna Godavari delta. Highest rate of erosion was found along the Krishna Delta recording 68 m erosion in a 43 years period. The High erosion is not concentrated in a specific area, but scattered some part of the coast with small stretches. No

Change area is found more than erosion and accretion. It seems over entire coast, and Medium accretion trends during this period were also spread middle of the coast. However, the significant changes with large erosion and accretion were confined to River mouths. High accretion was recorded in between Krishna and Godavari Delta. The maximum accretion rate was recorded in Godavari River Mouth with net accretion of 66m, predominantly; maximum changes were recorded between the coastal stretches of Krishna and Godavari Delta (Figure 3).

The distribution of the shoreline change classes during 1972-2015 recorded 138.94 km coastline length as high erosion contributing to 12% of total coast. Medium erosion recorded 174.74 km length corresponds to 15% of the total coast. 51% of the total coastline area could not find any changes during this period; it comes 599.30 km of the total area. Whereas, medium accretion class were recorded 137.77 km length corresponds to 11% of total coast and 128.01 km coastline length as high accretion contributing to 11% of the total coast (Figure 4).

Coastal regional elevation

The coastal regional elevation is derived along the coastline of Andhra Pradesh using ASTER (Advanced Space borne Thermal Emission and Reflection Radiometer) [20] data depicting the maximum area under the very high vulnerable category (less than 3). Very High vulnerability (low elevation) was recorded in southern parts of the region, especially Pulicat, Koduru, Krishna and Godavari Delta. Lowest elevation was found along the Godavari River Mouth recording 8m below mean sea level. The High vulnerability (low elevation) is concentrated in a specific area of Kakinada, Dharmavanam, but scattered over entire coast with small stretches. Moderate and Low vulnerability trends were also spread the Northern coast. Very Low vulnerability (High Elevation) was recorded in Vishakhapatnam coasts. The Highest elevation was recorded in Vishakhapatnam with elevation of 72 m along the coast.

The distribution of the elevation vulnerability classes along the coastline (Figure 5) recorded 634.95 km coastline length as very high vulnerability contributing to 57% of total coast.

High vulnerability recorded 176.46 km length corresponds to 16% of the total coast. 10% of the total coastline area could find Moderate vulnerability; it comes 111.18 km of the total area. Whereas, Low and very Low vulnerability classes were recorded 181.05 and 12.24 km lengths respectively with 16% and 1% of the total coast.

Coastal slope

Slope is one of the important parameter for calculating CVI; Coastal slope mainly controls the inundation. In gentle slope may cause high vulnerability and steep slope comparatively less. The

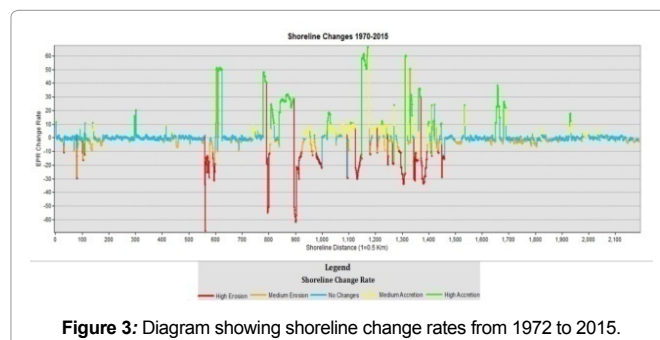
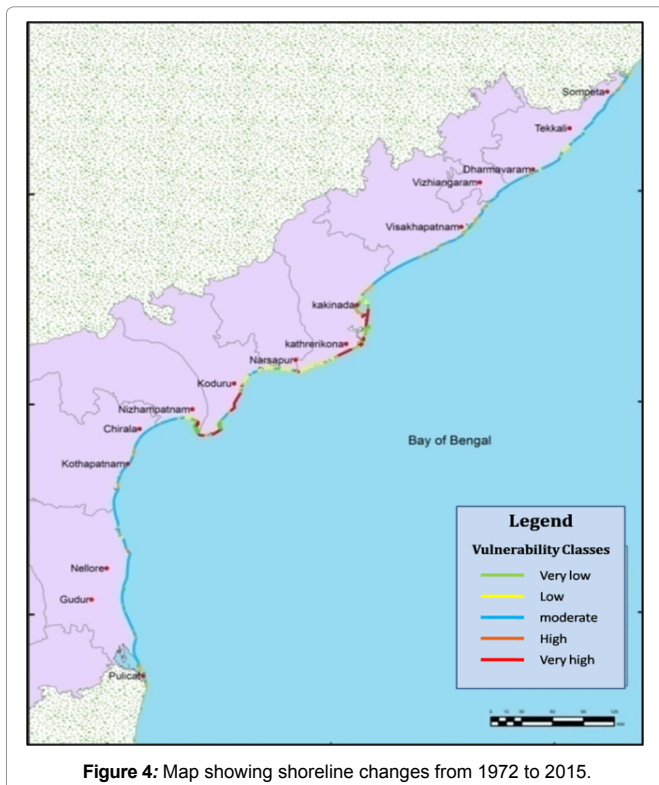


Figure 3: Diagram showing shoreline change rates from 1972 to 2015.



coastal slope is extracted along the coastline of Andhra Pradesh using GEBCO (General Bathymetric Chart of Oceans) data portraying the maximum area under the very low vulnerable category (above 60°). Very Low vulnerable (Steep Slope) was recorded in almost parts of the region, especially Nellore, Chirala, Vishakhapatnam and Vizianagaram. Highest degree of steepness was found along the Vishakhapatnam recording 87° slopes because of eastern ghat. The Low vulnerable area is concentrated in Kothapatnam, Kakinada, and scattered over southern coast with small stretches. Moderate vulnerability trends were spread the Koduru coast. Low and Very Low vulnerability (Gentle Slope) was recorded in very small stretches of the Godavari Delta. The Lowest Degree of slope was recorded in Kakinada with 6° Slope along the coast.

The distribution of the elevation vulnerable classes along the coastline recorded 1.20 km coastline length as very high vulnerability contributing to below one percentage of total coasts. High vulnerability classes recorded 2.55 km length corresponds to below one percentage of total coasts.

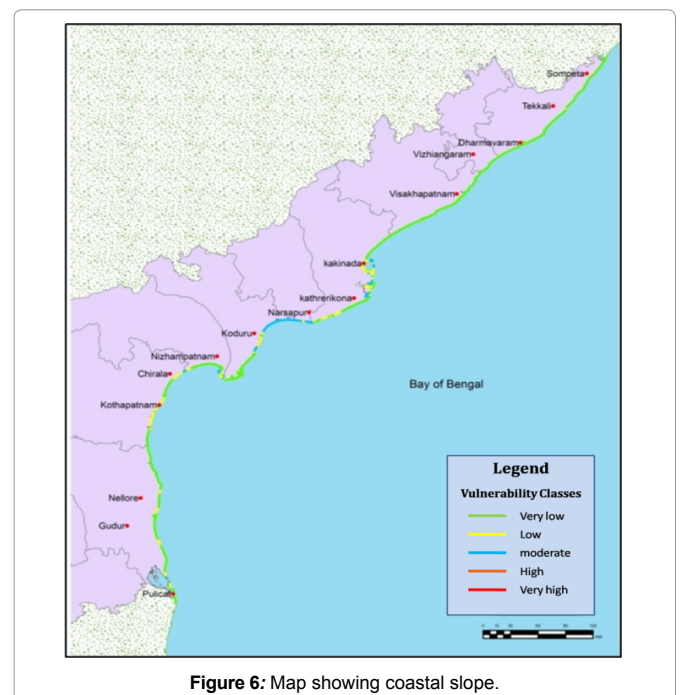
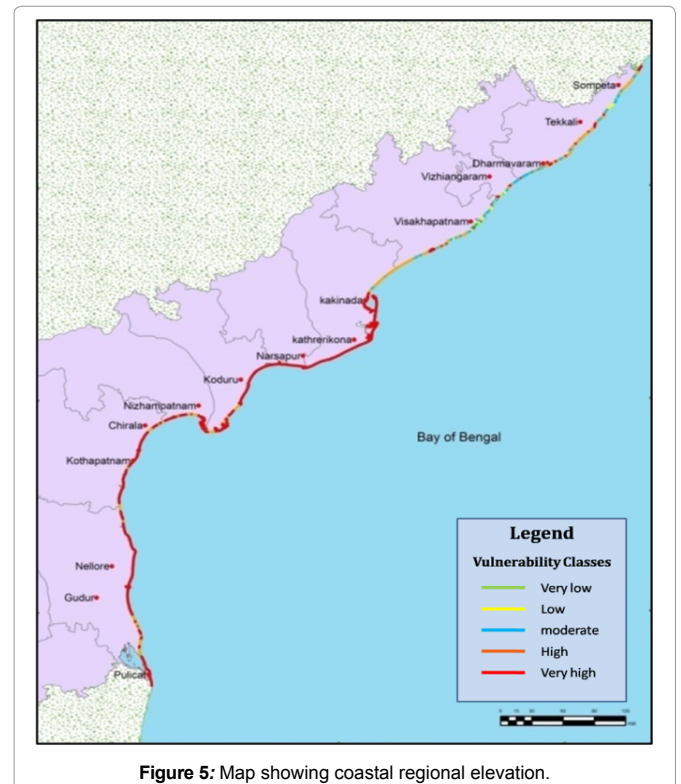
11% of the total coastline area could find Moderate vulnerability; it comes 117.81 km of the total area. Whereas, Low and very Low vulnerable classes were recorded 209.10 and 785.40 km lengths respectively with 19% and 70% of the total coast (Figure 6).

Coastal geomorphology

The geomorphology variable expresses the chance of erosion of different landform types. The coastal geomorphology is an important parameter which controls coastal process and reflect the impact of these process. Geomorphology data were collected from Bhuvan thematic map service with level II classification. The Low vulnerability to geomorphology was recorded only in Vishakhapatnam. Moderate vulnerability to geomorphology trends were spread the Sompeta,

Dharmavanam and Southern Vishakhapatnam coast. High vulnerability to geomorphology was recorded in Godavari Delta and southern part of the study area (Nellore, Pulicat, Kakinada). Very High vulnerability area recorded only in Krishna Delta.

The distribution of the geomorphologic vulnerability classes along the coastline (Figure 7) recorded 233.07 km coastline length as very high vulnerability contributing to 21% of total coasts. High



vulnerability recorded 558.45 km length corresponds to 50% of total coasts. 17% of the total coastline area could find Moderate vulnerability, it comes 186.15 km of the total area. Low vulnerability classes were recorded 137.70 km 12% of the total coast.

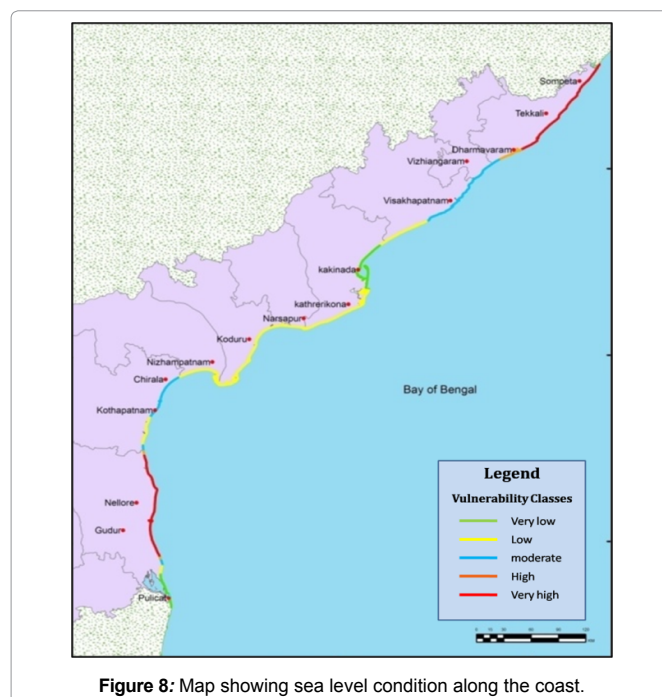
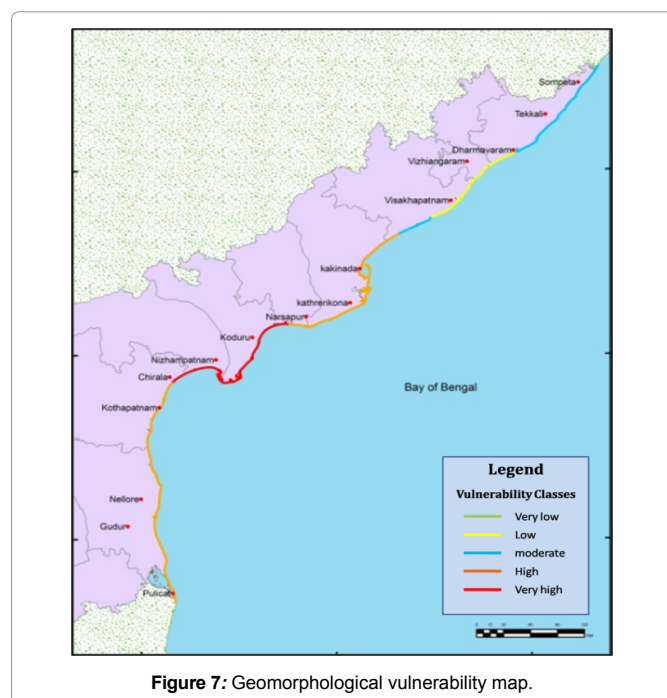
Sea level rise

Mean sea level an average level for the surface of one or more of Earth's oceans from which heights such as elevations may be measured. The Mean Sea Level Rise data is collected along the coastline of Andhra Pradesh from GLOSS (Global Sea Level Observing System) data depicting the maximum area under the low vulnerability category. Very High vulnerability was recorded in southern and Northern part of the region, especially Nellore in South, Sompeta and Thekkali in North. High vulnerability is concentrated in Vizianagaram. Moderate vulnerability shows were in Vishakhapatnam and Chirala. Low vulnerability was recorded in Nizampatnam, Koduru, Narsapur and Northern Kakinada cost. Very Low vulnerability was recorded in Pulicat and Kakinada coasts. The Highest Sea level rise was recorded in top most point of the coastline with Rise rate of 5 cm per year along the coast and the Lowest Sea level rise was recorded in Pulicat coast with rise rate of 0.8 cm per year (Figure 8).

The distribution of vulnerability classes on the basis of Mean sea level along the coastline recorded 182.01 km coastline length as very high vulnerability contributing to 15% of total coast. High vulnerability recorded 132.86 km length corresponds to 11% of the total coast. 17% of the total coastline area could find Moderate vulnerability; it comes 213.96 km of the total area. Whereas, Low and very Low vulnerability classes were recorded 537.20 and 171.54 km lengths respectively with 43% and 14% of the total coast.

Tidal range

The tidal range is the vertical difference between the high tide and the succeeding low tide. The typical tidal range in the open ocean is about 0.6 m (2 feet). Closer to the coast, this range is much greater.



Very High vulnerability was recorded in southern part of the region, especially Pulicat. High vulnerability is concentrated between Gunduru and Koduru coast. Moderate vulnerability shows were in Godavari delta, Dharmavaram and Sompeta. Low and Very Low vulnerability was not found in the study area. The Highest Tide range was recorded along the coast of Vishakhapatnam, with range of 1.7 m and the Lowest Sea tide range was recorded in Pulicat coast with range of 1.2 m.

The distribution of vulnerability classes on the basis of Tide range along the coastline (Figure 9) recorded 62.87 km coastline



Figure 10: Map showing significant wave height along the coast.

length as very high vulnerability contributing to 5% of total coast. High vulnerability recorded 656.54 km length corresponds to 53% of the total coast. 42% of the total coastline area could find Moderate vulnerability; it comes 518.13 km of the total area

Significant wave height

On the basis of vulnerability classification the shoreline along the study area found only medium low and very low vulnerability classes. Moderate vulnerability was recorded in Pulicat, Nellore, and Sompeta. Moderate vulnerability shows were in between Nellore and Godavari Delta, Dharmavanam and Sompeta. Very Low vulnerability was concentrated in Vishakhapatnam coast. The Highest wave height was recorded along the coast of Pulicat, with range of 0.8 m and the lowest wave height was recorded in Vishakhapatnam coast with range of 0.1 m.

The distribution of vulnerability classes on the basis of significant wave height along the coastline (Figure 10) recorded 207.15 km coastline length as very low vulnerability contributing to 19% of total coast. Low vulnerability recorded 704.82 km length corresponds to 64% of the total coast. 17% of the total coastline area could find Moderate vulnerability; it comes 183.65 km of the total area.

Estimation of coastal vulnerability

Coastal vulnerability index (CVI) is one of the methods for assessing costal vulnerability. The index allows the seven physical variables to be related in a quantifiable manner. This method yields numerical data that cannot be directly equated with particular physical effects

Very High vulnerable area was recorded in southern parts of the study area with small stretches in Nellore and Narsapur. The High vulnerable area is concentrated in Nellore, Kothapatnam and southern part of Kakinada. Moderate and Low Vulnerable trends during this period were also spread across the entire coast and these are recorded more in Sompeta, Kakinada, Koduru and Kothapatnam. Very low

vulnerable was recorded in Vishakhapatnam and Vizianagaram coasts. The highest Vulnerable Index is recorded in Pulicat with 32.07 index value and lowest vulnerable index was recorded in Vishakhapatnam with 2.26 index value the results indicate that about 3% is categorized under very high vulnerability; it comes 34.17 km of the total coastline. High vulnerable area recorded 147.90 km coastline length as contributing to 13% of the study area. Moderate vulnerable area find 341.7 km contributing 30% of the total coastline. 33% of the total area could find low vulnerable and it comes 367.71 km length of the study area. Very low vulnerable areas found along the study area were 242 km length corresponds to 21% of the total coast.

The Figure depicting the distribution of the CVI along the study area (Figure 11). It reveals that very high and high vulnerable classes were dominantly constrained to the Nellore and West Godavari districts (Nellore, Narsapur and Sompeta) correspond to 16% of total coast. The parameters: shoreline change, Tidal Range, Coastal elevation, Mean sea level are contributing these areas with high vulnerability. Remaining areas were recorded very low to moderate. Vishakhapatnam district was recorded very low compared to other districts; this may be probably due to high elevation, cliffs and rocky slopes.

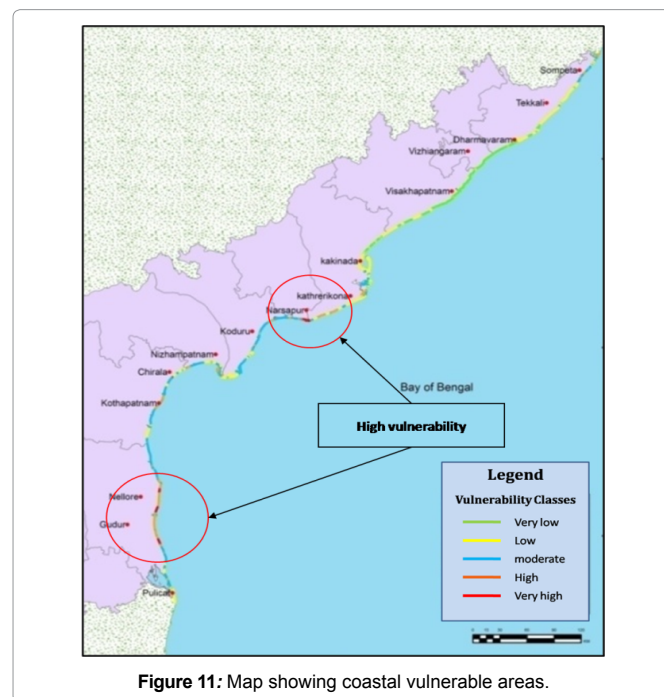


Figure 11: Map showing coastal vulnerable areas.

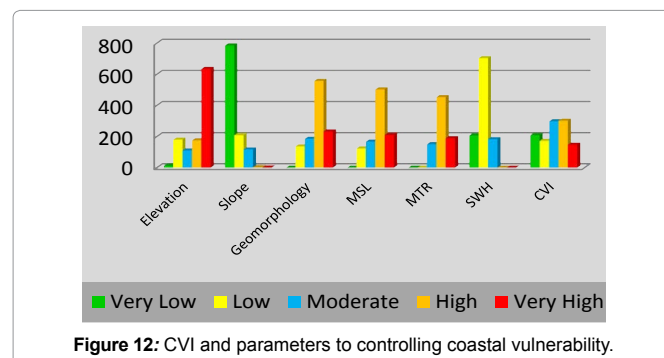


Figure 12: CVI and parameters to controlling coastal vulnerability.

The figure given below (Figure 12) is showing is the vulnerable rates controlling to CVI, Elevation, Geomorphology, MSL, MTR are recorded high vulnerability compare to other parameters. These parameters are controlling factors for coastal vulnerability.

Conclusion

Data and techniques used in this study provide useful insight in assessing the coastal vulnerability and morphological changes in the coastal environs of the study area due to climatic changes, mostly by sea level rise and shoreline erosion. The sea level rise and tides are more controlling to vulnerability than other parameters. This study found 16% of the total coastal stretches had recorded high vulnerability in southern part of study area (Nellore, Pulicat and Narsapur). The Northern parts of the study area shows low vulnerability due to elevated topography of the Eastern Ghats. The map shows high vulnerability areas are continually affected by cyclone and storm surge. Sea level is increasing frequently and in future it will be harmful to human activities as well as biodiversity, which is close to the coastal region. During the last 15 years over eight cyclones and surges happened in Andhra Pradesh which affected more in southern Andhra between Vishakhapatnam and Pulicat Lake. The study envisage that the areas which are high vulnerable may get damaged by cyclone surge or due to long term climatic changes.

Nellore and Part of Pulicat Lake is a major fishing zone in Andhra Pradesh and its population is around 29, 63,577. Most of them are concentrated in fishing and related activities, which all are under vulnerability. The small climatic changes may affect their livelihood. Kakinada and Narsapur region is one of the highest deltaic planes in India, the area have rich biodiversity and mangrove forests. The sea level rise will affect the environment, the area might become submerged and it will harm mangroves and biodiversity. Population of 3, 12,538 are also in the vulnerable zone.

Results of this study provide useful inputs for the coastal zone management and planning. Further, maps produced in the study aid in the coastal disaster management and mitigation. This study can be further improved by using the high-resolution satellite and topographic data.

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Top

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